Thermal and Fluid Analysis and Design of the NanoRacks Airlock ® Module

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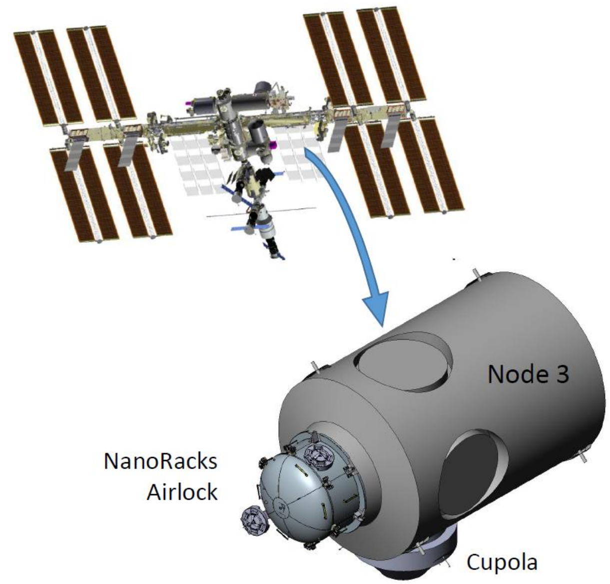
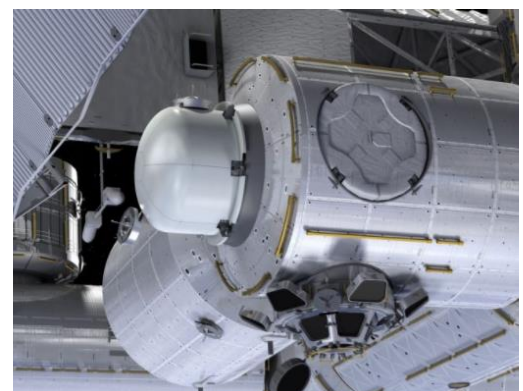
Introduction

- Airlock provides a bigger doorway to space on the ISS
  - Increase payload deployment volume by 5x over JAXA Kibo module
  - Deploy cubesats, smallsats, and scientific instruments
  - Permanent commercial module on ISS
  - May be relocated to commercial space station after ISS retirement
  - Scheduled for launch in 2019 on SpaceX Falcon 9/Dragon





An artist's rendering of the NanoRacks airlock attached to the *Tranquility* module.
Image Credit: NanoRacks

Airlock on Port Side of Node 3

Airlock Requirements

- NanoRacks and ATA worked with NASA, ISS, Boeing to define and maintain all IRB thermal requirements and temperature limits for various launch and on-orbit phases
- IRB defines:
  - Analysis parameters and load cases to consider
  - Temperature limits (e.g. to preclude condensation)
  - Heat transfer limits to ISS
  - Human safety factors (e.g. touch temperature limits)
  - IMV airflow parameters and air velocity limits

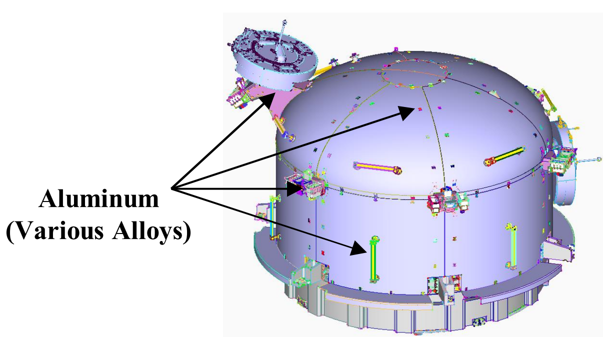
Temperature Limits Per Mission Phase

- Dragon Free-Flight
  - Material and Non-Op limits
- Dragon Trunk on Node 2 and Transfer to Node 3
  - External Touch Temperature limits
- On SSRMS at Node 3 Pre-Berthed
  - PCBM and ACBM mating limits
- Node 3 Berthed and Unpressurized
  - Condensation and Touch Temperature limits
- Berthed and Pressurized on Node 3
  - On-Orbit Survival during Planned 6-hour Power Outage
- SSRMS Payload Deployment Operations
  - Touch Temperature limits

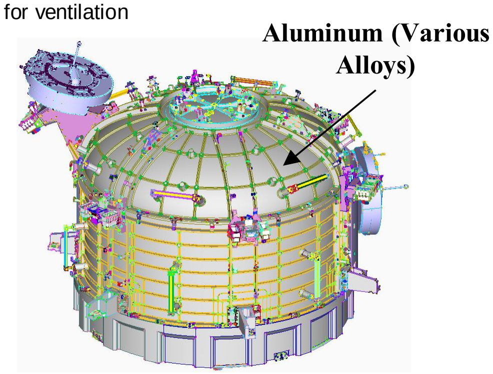
Airlock Design

Å Bell jar design
- ï Primary structure
  - Å Passive common berthing mechanism (PCBM) ï standard, flight-proven hardware
  - Å Pressure shell ï provides habitable environment
  - Å Launch vehicle flight support equipment (FSE) ï designed and built by SpaceX
  - Å Power and video grapple fixture (PVGF) ï interface to ISS Space Station Remote Manipulator System (SSRMS)
- ï Secondary structure
  - Å Internal outfitting (e.g. seat tracks, avionics support structure)
  - Å Micrometeoroid orbital debris (MMOD) shielding
  - Å IVA/EVA handrails and mounts
  - Å Payload support structure and GOLD-2 Connectors

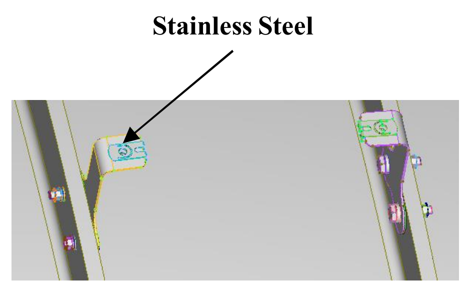
Å Thermal control system (TCS)
- ï Passive thermal mechanisms
  - Å Multilayer insulation (MLI) beneath MMOD
  - Å Coatings
- ï Active thermal mechanisms
  - Å Shell heaters
  - Å Air ventilation while berthed to Node 3 via Intermodular ventilation (IMV)
    - ï Discharge and return diffusers for ventilation



Airlock CAD

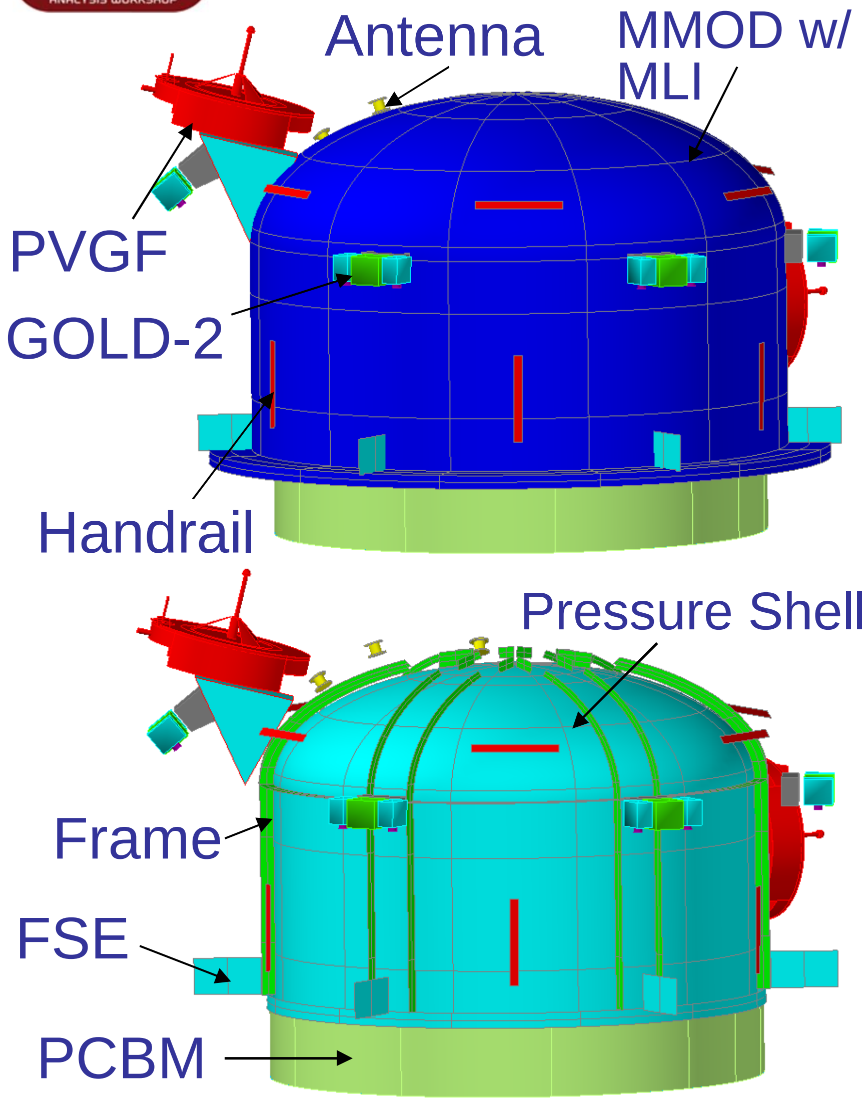


Airlock CAD (MMOD Not Visible)



Clips and Bolts used between MMOD and Pressure Shell

Airlock Thermal Model



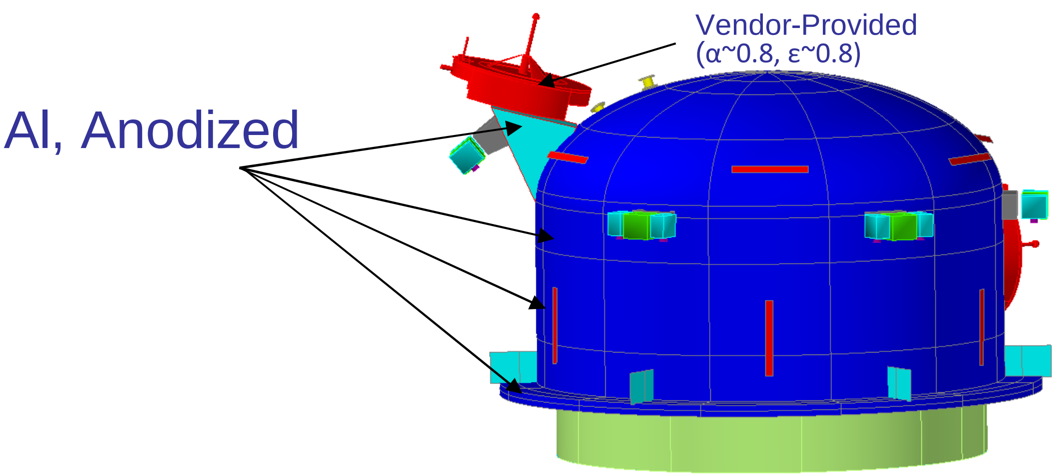
Airlock Thermal Desktop Simplified Model

- Simplified thermal model
  - 500 nodes
  - 300+ cases assessed
    - Different phases
    - YPR attitudes and articulating joints
    - Beta angles: 75ęto -75ę
    - Design iterations
  - Integration with vendor-provided models
- Modeling assumptions
  - Hot = 450 BTU/hr ft^2 solar, 81 BTU/hr ft^2 earth IR, 0.4 albedo, EOL surface properties
  - Cold = 419 BTU/hr ft^2 solar, 65 BTU/hr ft^2 earth IR, 0.2 albedo, BOL surface properties

Airlock Thermal Material Properties

Material Name	Density, kg/m³	Specific Heat, J/kg/K	Conductivity, W/m/K
AL (Varied)	2770.	921.6	121-173
Stainless Steel	8030.	504.	16.3

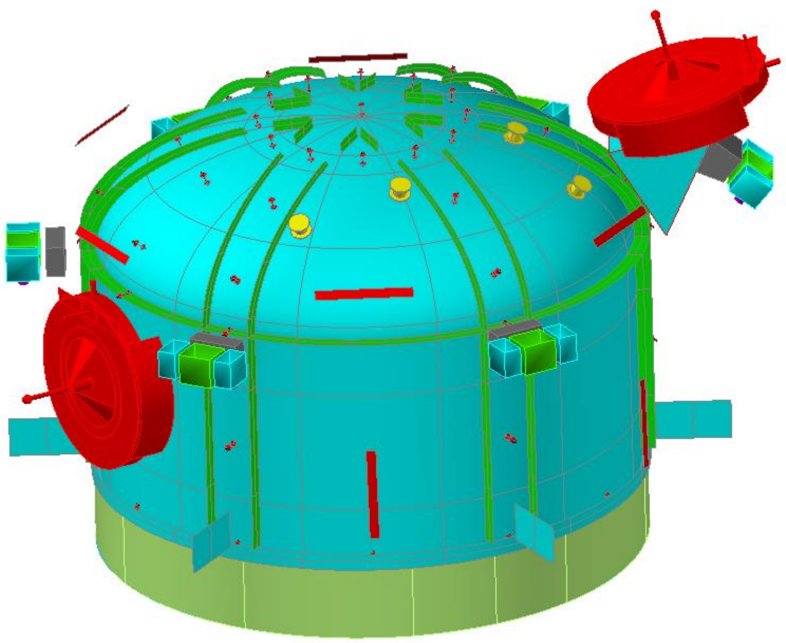
Material Name	Absorptivity	Emissivity
AL, Anodized (Varying)	0.350 - 0.760	0.820 - 0.880
Betacloth	0.400	0.600
Nickel Plated	0.440	0.120
Stainless Steel	0.470	0.140



Airlock Thermal Desktop Simplified Model

Airlock Thermal Analysis Approach

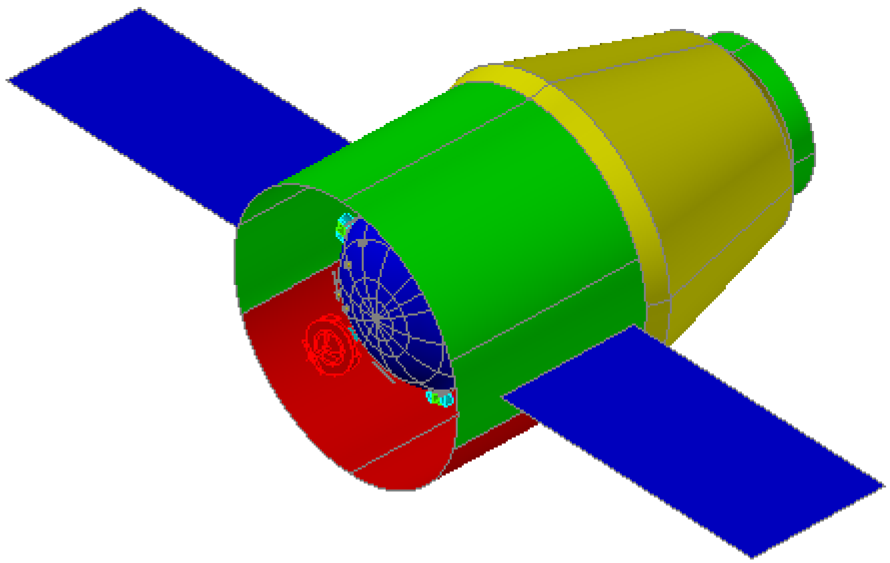
- Heaters
  - Thermostatically controlled shell heaters with fault tolerance
  - 80% heater duty cycle
  - Heaters placed in regions of maximum heat leakage currently
    - Most leakage occurs near PCBM and PVGF
    - Need to be refined via detailed model
  - 800 W of total heater power
    - Sized to survive and maintain components during worst case cold environments and non-op 6-hour cooldown



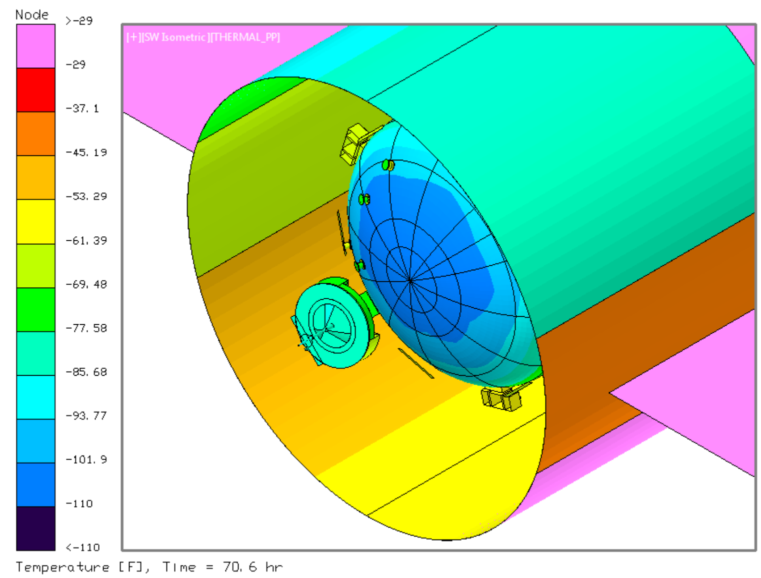
Airlock Thermal Desktop Model with MMOD Shield removed and Heater circuits visible

Airlock Design for Dragon Free-Flight

- Vendor-provided components like Antenna and PVGF have slight exceedances on the cold side
  - Mitigate through component TVAC testing



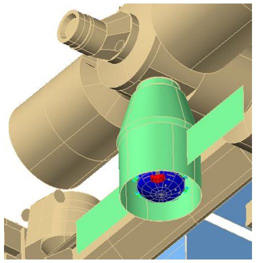
Dragon Free-Flight Thermal Desktop Model



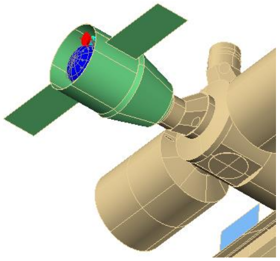
Dragon Free-Flight Temperature Contour Showing Antenna Exceedance on Cold Side

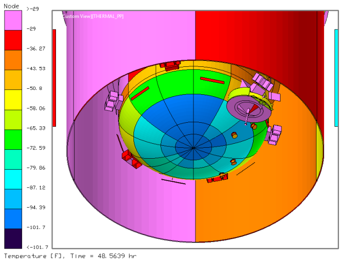
Airlock Design for Node 2 Berthing

- Variable Dragon on Node 2 berthing schemes considered
  - Node 2 Nadir
    - No exceedances
    - Best option

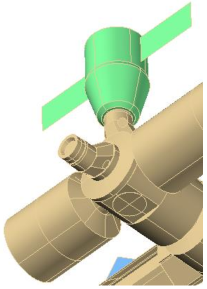


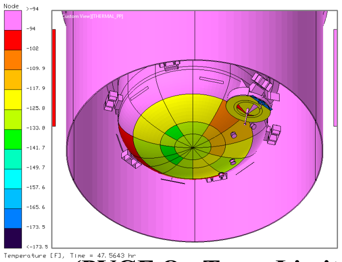
  - Node 2 Forward
    - Some exceedances for antenna
    - Bounded by dragon free-flight





  - Node 2 Zenith
    - Numerous exceedances





(PVGF Op Temp Limit: -94˚F)

Dragon Berthed on Node 2 Thermal Desktop Models

Dragon Berthed on Node 2 Temperature Contours

Airlock Design – Airlock on Node 3

Å When berthed on Node 3, Airlock acts like a radiator

ï Radiator Area >100 ft^2

ï Minimize heater power required to meet condensation temperature requirements for internal components

Å Also minimize heater power for 6 hour cooldown requirement

ï Potential design solutions

Å Lower MMOD Ŭ/Ůratio

Å Black anodized aluminum/betacloth for MMOD stovepipe

Å Reduce MLI Ů* from 0.03

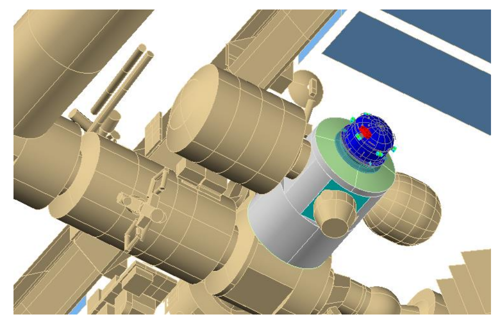
Å Increase thermal isolation between MMOD and Pressure shell since most heat loss is conductive ï this is the most robust solution

Å Add thermal isolation to PVGF interface

ï Heater requirements

Å 80% duty cycle

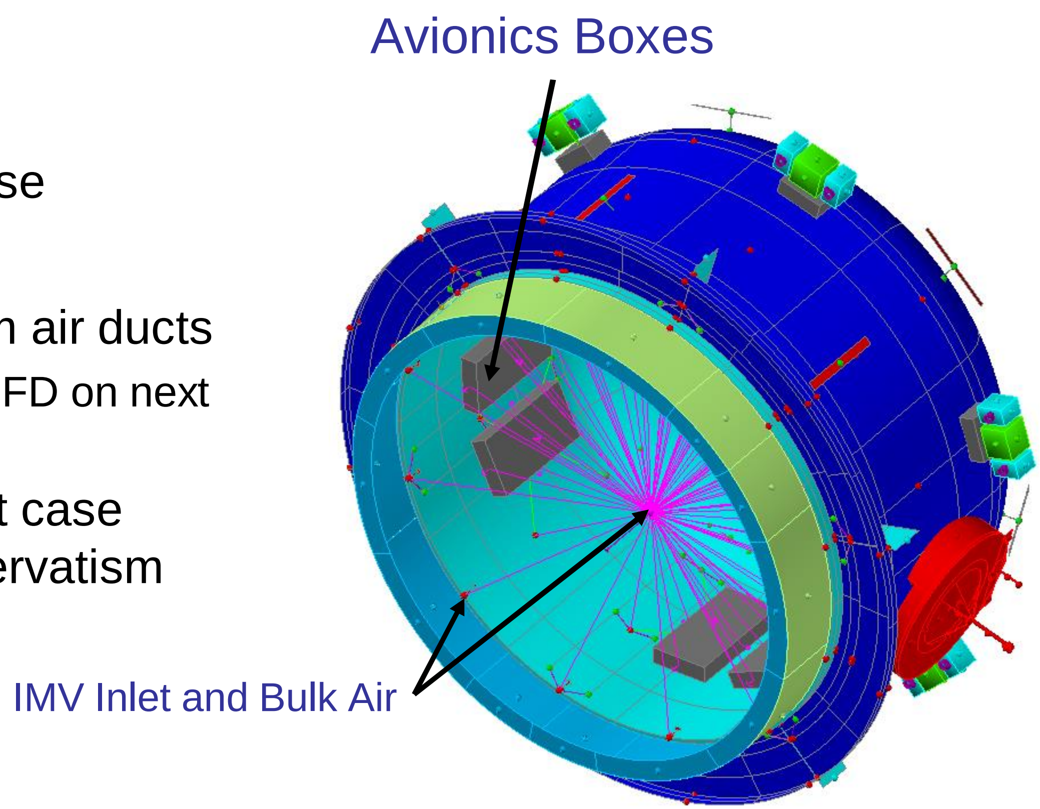
Å Place heaters in regions with greatest conductive loss



Airlock Berthed on Node 3
Thermal Desktop Model

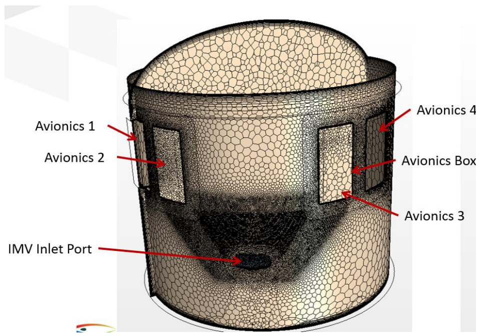
Airlock Design - Airlock on Node 3

- Other power sources
  - Avionics
    - 200 W dissipation
    - Still in development
    - Only used for hot case
  - IMV
    - 100 W heat flow from air ducts
      - Calculated from CFD on next slide
    - Not used for cold/hot case predictions for conservatism

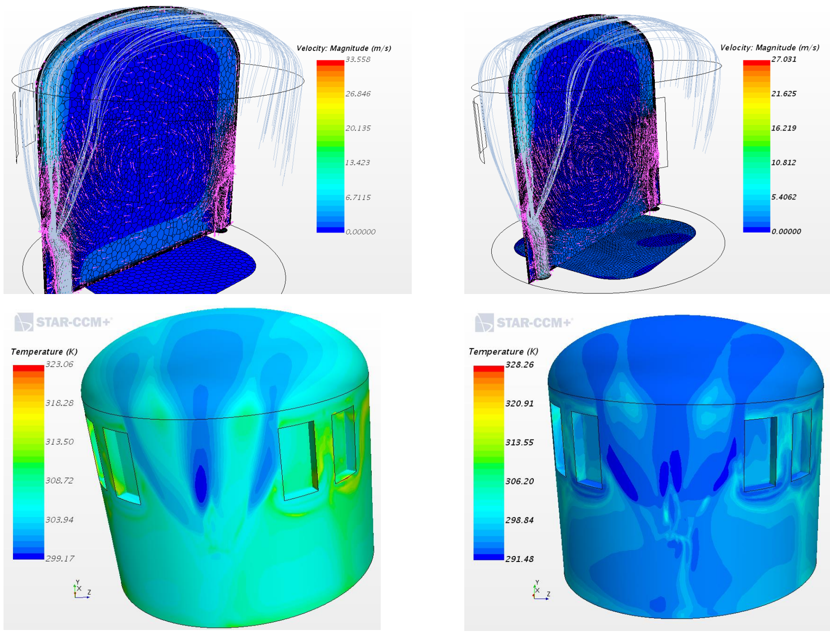


Airlock Thermal Desktop Model with MMOD Shield, Avionics, and IMV Visible

Airlock Design – IMV CFD on Node 3



Mesh with Prism Layer



Velocity and Temperature Gradients with Hatch Closed (Left) and Open (Right)

Å CFD performed on Node 3 with 4 avionics boxes and detailed IMV ducts

ï Estimated bulk heat transfer coefficients for use in Thermal Desktop

$$\overline{h}_c = \frac{q}{\left|\overline{T}_{surf} - \overline{T}_{exit}\right|}$$

ï Demonstrated volume of stagnant air < 5% per NASA requirements

ï STAR-CCM+ solver with SST turbulence model and average Y+ = 2.25

ï Boundary Conditions

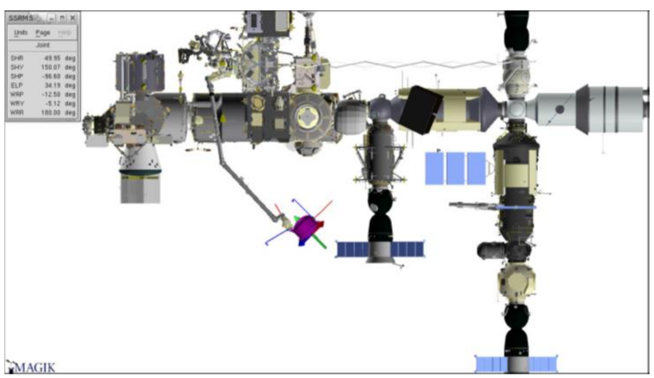
Å IMV Inlet with varying CFM (Closed or Open Hatch), Boundary Temperature, P = 1 atm

Å Pressure outlet with Boundary Temperature, P = 1 atm; Hatch open or closed

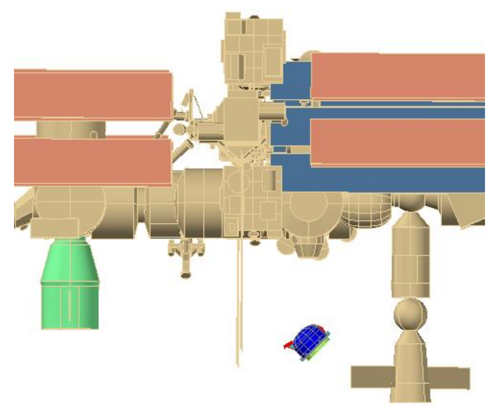
Å Constant heat flux on wall boundaries (except IMV duct walls)

Airlock Design – SSRMS Deployment

- There are minimal temperature exceedances during payload deployment
  - During certain off-nominal attitudes, sun has direct view to internal components
    - Will be mitigated to limit operations during extreme orbital conditions
  - Antenna and handrail have slight exceedances on cold side during some nominal +XVV orbits
    - Mitigate through testing



SSRMS Payload Deployment CAD



SSRMS Payload Deployment Thermal Desktop Model (SSRMS not used in analysis)

Airlock Thermal Testing Approach

Å Antenna Unit-Level Thermal Testing

- ï PQ thermal testing at ambient and vacuum pressure with 16 and 4 cycles respectively to demonstrate integrity
- ï 5e¿C (9e¿F) margin and 11e¿C (20e¿F) uncertainty
- ï Critical component that far exceeds current design limits
- ï Designed with guidance from MIL-STD-1540E

Future Design Work

Å Detailed heater layouts

  ï 6-hour cooldown requirement

  ï Double fault tolerance

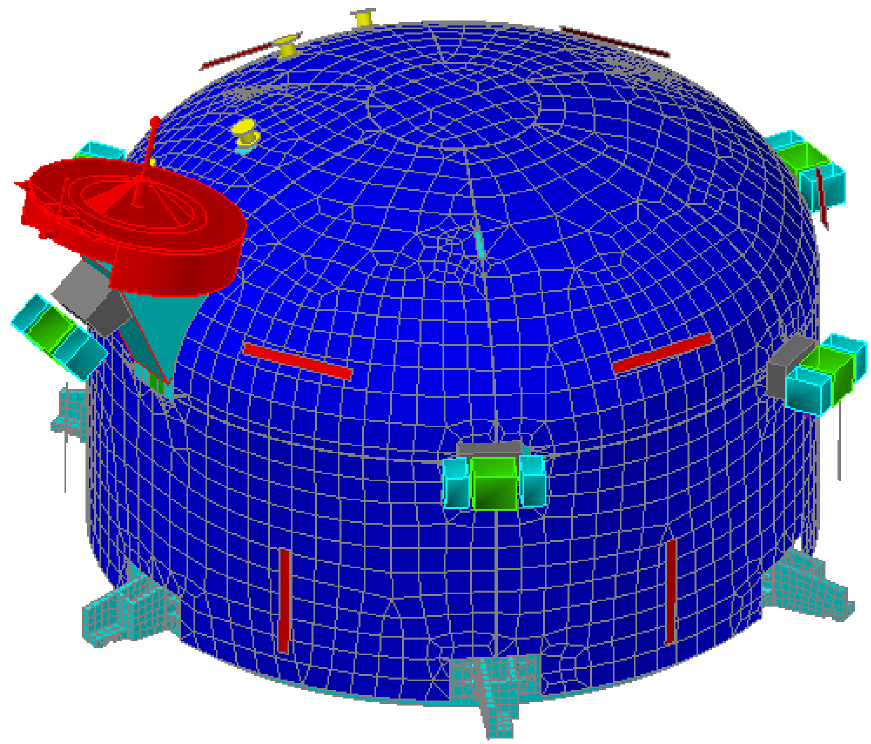
Å SpaceX detailed dragon model integration

Å Development of detailed model

  ï 10k nodes

  ï Analyzed for worst case attitudes and beta angles

Å Complete suite of analyses to demonstrate compliance with ISS IRB



Airlock Detailed Thermal Desktop Model (Under Development)

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